CHARACTERIZING EXTREME ENVIRONMENTS FOR ARMY TESTING

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ABSTRACT

Army Regulation (AR) 70-38 publishes standards for temperature and humidity in different environments, but there are other important environmental features such as general climate, terrain character, and biological diversity, that are also important for successful Army materiél testing and training. An initial tropical test site study was necessitated by the closure at the end of 1999 of all U.S. Army tropical testing and training facilities, which had been located in the Republic of Panama. In the process of searching for a replacement for the lost tropical testing facilities, the Army and its natural environment testing activity, Yuma Proving Ground YPG), developed a better scientific understanding of how geographic analysis could enhance the Army's ability to test and train in a natural environmental setting. A list of 14 criteria was developed that characterizes any site as to its ability to support all testing missions. This list was initially employed to screen Hawai'i and Puerto Rico for areas that could support components of the tropical testing mission. A similar approach was taken in analyzing current Army desert testing and training environments in a study that undertook detailed site characterizations of Yuma Proving Ground and the National Training Center (NTC) at Ft. Irwin.

1. INTRODUCTION

The major military powers of the world recognize the need for military equipment and materiél capable of performing in the harshest of natural environmental conditions, but it has been a hard lesson only learned over time on the battlefield at significant cost. As starkly illustrated by the Napolean's invasion of Russia in 1812, and subsequently confirmed by the German Army experience during Operation Barbarossa in World War II, the lack of the right equipment in an extreme environment, such as the Russian winter, can be fatal (Winters., 1998). The U.S. experience in Southeast Asia and the Middle East over the past four decades reconfirmed the need to test the performance of new equipment under the demands of extreme environments.

For the modern U.S. Army to accomplish the diverse missions it is assigned today, soldiers and their equipment must be capable of functioning in all types of terrain and in any environment. To meet this requirement, the Army must define the natural conditions that pose the greatest threats to operations and then identify where these conditions are found globally. In general, the Army addresses this requirement by classifying extreme natural environments into the three broad categories of *hot and dry, warm and wet*, and *extremely cold* – or, in more common environmental terms, desert, tropical, and arctic environments. Clearly, the Army must fully recognize and understand the challenges presented by deserts, tropics and arctic regions. This requirement challenges the Army's people, equipment, and training programs. Science, coupled with operational experience, helps identify the specific challenges each of the extreme environments pose for military operations. To prepare for the full spectrum of possible operations, the Army develops and tests the functionality and performance of its equipment in extreme environments to ensure that America's soldiers have the best equipment that modern technology can provide. Then, the Army trains its soldiers in the use of that equipment, according to current military doctrine, under the harshest of environmental conditions.

2. ENVIRONMENTAL TESTING

Given its global missions and responsibilities, the U.S. Army has a well-established practice for testing its materiél, equipment, and systems throughout the entire range of potential operating environments. At present, mission responsibility for natural environment testing resides with the U.S. Army Yuma Proving Ground, AZ. Testing activities in arctic and desert environments are conducted at facilities within the US,

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cold-climate testing at Ft. Greeley, AK and desert testing at Yuma Proving Ground, AZ. One of the provisions of the 1977 Panama Canal Treaty required that the U.S. military withdraw from, and relinquish the use of, its military installations and facilities in the Republic of Panama on 31 December 1999, including the well-established US Army Tropic Test Center that had been operating within the former Canal Zone area since the 1930s. Since 1999, a limited degree of tropic testing has been undertaken at Schofield Barracks, HI, although the environment there does not fully meet mission requirements.

The specific test site evaluation process developed involved translating the mission requirements of materiél testing engineers into quantitative and qualitative environmental criteria that could be incorporated into a site-selection decision-making model. The testing and evaluation of equipment and systems in the natural environment is conducted using accepted laboratory protocol and established engineering practices to assure experimental control, repeatability, and validation of test results. Many aspects of the testing process are conducted over long periods of time and, therefore, a fundamental requirement for a test facility is the presence of the desired environmental conditions on a year-around or seasonal basis, as appropriate. Testing also requires a well-characterized and understood suite of field sites that provide specific environmental conditions that are fully representative of those in which soldiers, systems, and materiél may encounter during military operations. These test sites must, in turn, be capable of efficiently accommodating broad categories of military systems and test activities.

Historically, environmental testing has been divided into three broad types of activity: (i) long-term exposure testing of materiél, equipment, vehicles, weapons, and munitions; (ii) technical performance and reliability testing of equipment and systems under ambient environmental conditions; and (iii) system and human performance evaluation under operational conditions. In addition to the ongoing testing requirements in these three areas, emerging technologies must be fully tested. This type of testing includes: sensors (airborne/space-borne and man-portable systems); information, data networking, and communication technologies based on electromagnetic transfer; cloaking and reduced signature technologies; and product improvements of existing systems. All of these technologies are highly sophisticated and complex. As such, testing and evaluating new technology requires a thorough understanding of the environmental factors affecting their technical performance.

Additionally, there will be increased focus on dual-use or multi-use technologies that have high pay back, such as environmental technologies for landmine, IED, and UXO detection/location. All of these technologies are highly sophisticated and complex. As such, test and evaluation of this new technology will require a thorough understanding of the environmental factors affecting their technical performance as well as the synergistic environmental effects that challenge equipment operability and reliability.

Future test technologies to assess performance will require increased sophistication, one aspect of which will be the increased reliance on modeling and simulation in the virtual environment to support test and evaluation. Additionally, the test community will have greater flexibility in meeting customer requirements for test data and evaluation through new approaches to modeling and simulation. Development of digital environmental reference models for modeling and simulation is currently under development as a series of Master Environmental Reference Sites (MERS), which are located at extreme climate test sites under the command of YPG. These carefully characterized MERS are the reference environmental sites for the Virtual Proving Ground (VPG).

3. GEOGRAPHIC LOCATIONAL ANALYSES

At the request of Yuma Proving Ground, and under the auspices of the Army Research Office, panels consisting of scientists from different academic disciplines have been addressing the very important question: *How does one find the best natural environmental conditions to achieve the maximum benefit from field testing of equipment and materiél?*

The obvious assumption built into this research question is that the process developed for studying one environment is equally valid in other environmental settings. This assumption has been analyzed by both the testing community and by environmental scientists and found to be valid. Specific details of the analysis will be presented in the process of discussing the results.

An 8-step process (Table 1) was employed in the geographic analysis that involves translating the requirements of materiél testing engineers into a combination of quantitative and qualitative environmental criteria that subsequently could be incorporated into a site evaluation and decision-making model. The first step of the analysis is to define the critical climatic, physical, and biological characteristics of the 'ideal' test environment. Table 2 presents such an analysis for the tropic test case and Figure 1 illustrates the results of this analysis. The most significant finding of initial Tropic Test Center relocation study (King *et al.*, 1998; 2004a) was the conclusion that there were few ideal locations in the world that could support the broad tropic test

requirements of the Army and none of these sites existed within U.S. territory. This result leads either to the end of the research, with a negative result, or expands the investigative approach, which in the tropic test case provided the basis for an expanded study (King et al., 1999) to develop a site selection model based upon a decision-tree strategy methodology.

To implement this methodology, a hierarchy was developed in which each of 14 environmental criteria of Table 2 was categorized in one of three ways: (i) an essential environmental factor, or (ii) an element that would enhance testing, but could be absent by accepting some decrement to the value of the test, or (iii) a need to avoid conditions that could adversely impact testing. A general decision tree was used, with each factor weighed from highest to lowest priority according to the criteria applicable to a specific test.

3.1 The Tropical Study

For the tropical study, essential parameters included: diurnal and annual temperature (mean and ranges), annual and monthly precipitation level (mean and ranges), relative humidity, physiography (relief, slope, elevation range), and biotic communities (vegetation structure). Characteristics deemed highly desirable, but not critical, included: minimal effects of tropical cyclone (hurricane or typhoon) activity, seasonality (minimal dry season preferred), range of vegetation types (forest, swamp, grassland), range of landscape types (sea coast, coastal wetland, coastal plain, upland), well-developed and variable soil profiles (oxisols, ultisols, inceptisols, entisols), and range of stream sizes and flow regimes. Screening criteria resulting in elimination of otherwise acceptable locations include: intensive geologic hazards (active volcanism, seismic activity, landslides, mudslides), high tsunami/storm surge susceptibility, presence of extensive karst topography (limestone), frequent or large-scale disturbance of vegetation (natural and/or anthropogenic), presence of high levels of disease vectors, impacts of farming, industry or urbanization, and land use restrictions. The decision tree analysis was employed in evaluating regions to identify candidate locations for further analysis. Based on the 'Ideal Setting' criteria of Table 2 and the 'Decision Tree' process, Figure 1 became a primary finding of the initial tropical test study (King *et al.*, 1998, 2004a).

Model development continued with the recognition that each of the 14 environmental site parameters has a different level of influence or importance to each specific testing mission (Table 4). For example, as presented in Table 4, environmental exposure is a sub-category under equipment developmental testing. In a tropical setting; *temperature, humidity, rainfall,* and *fauna* are considered critical environmental factors, whereas a *canopy* is considered desirable but not essential. Conversely, the other nine *feature, slope* and *relief* as examples, are relatively inconsequential for the success of static testing and, therefore, a site should not be eliminated from consideration for this test mission because of the absence of *slope* and/or *relief*. It then follows, that by identifying first the critical, and then the desirable environmental characteristics for the accomplishment of each specific testing mission, it should be possible to optimize the location for each component of the testing mission.

The next level of analysis must address the issue that each site will meet each of the 14 criteria to a greater or lesser degree. To develop a systematic approach to solve this problem, a 0-4 rating scale was developed to assess the relative compliance of each environmental factor at each site as follows: 0 = Unacceptable - fails to provide required setting, 1 = Marginal - places severe limits on testing, 2 = Good - meets all critical and most desired criteria, and 3 = Ideal – *i.e.* capable of full support.

The concluding step in optimizing tropical testing site selection occurs in the application of the model to specific candidate sites in Hawai'i and Puerto Rico. This is accomplished by grading of each site for its overall ability to support each component of the testing mission. To accomplish this task one additional evaluation scale was developed, a scale that applied only the essential or important environmental conditions for a specific test (*i.e*., those that are listed in Table 4). This rating was necessary to evaluate the capability to conduct a specific test at a given location.

Each site could then be assigned an overall grade that reflected the capability of that site to support a specific testing mission based on only the environmental factors important to that test. The results of the grading process employed in the tropical test center studies are presented in Table 5.

An example of the site evaluation process, which was applied to 8 sites in Hawai'i and 4 in Puerto Rico, is illustrated in Table 6. In this case, for Schofield Barracks, HI, which lies on the Lelehua Plateau, between the parallel Ko'olau and Wai'anae mountain ranges in central O'ahu, about 20 km north of Honolulu. The East Range Training Area of Schofield Barracks, occupying the leeward slopes of the Ko'olau Mountains, exhibits progressively more local relief and steep slopes with elevation. The mountains are drained by perennial streams and well-developed, clay-rich soils mantle the area. The minimum elevation of East Range is 305m, thus moderating temperatures compared to lowland sites; the mean annual temperature here is 21.0°C. Rainfall over the base area ranges from 1200-2000mm and the relative humidity is moderate to high. A range of forest types, including tall

Table 1. Analytic Model for Test Site Evaluation. (from King *et al.*, 1998)

Process Goal	Study Activity
Define test mission	Testing community defines mission requirements in quantifiable environmental criteria.
Define environmental requirements	Select the key climate, physical, and biologic characteristics of the environment necessary to achieve the particular test mission
Select a hierarchy for analysis	Determine the importance of each environmental parameter to be used in analysis
Select geographic regions	Apply screening tools to a regional analysis.
Select environmental parameters	Analyze the test mission to identify the environmental parameters that apply to the specific mission needs.
Select sites	Scientific and practical considerations used to obtain candidate sites from selected regions
Rate sites for compliance with environmental criteria	Conduct a comparative evaluation of the local environment at each candidate site.
Rate sites by testing mission	Use critical criteria to grade each site against each component of the test mission to make a rating of testing capability

Table 2. Criteria for an Ideal Tropical Test Area (from King *et al.*, 1998; 2004a)

I. Climate
Precipitation: 2 to 6 meters (m) per year, > 0.1 m in driest month
Temperature (°C): 18 minimum, 27 to 40 average daily
Relative Humidity (%): Mean = 75, range = 75 to 90
II. Physical Setting
Relief: Elevation = Sea level to 1500 m, Site relief = 150 m minimum, Slope = 0 to 60 %, coastal location with lowlands.
Surface water: Perennial small (1-2 m) to medium (up to 20m) width streams, with nominal nominal velocities (<20m/s).
Soils: Oxisols, ultisols, inceptisols, minimum depth in the range of 10m
III. Biological Considerations
Vegetation Structure: Secondary tropical rainforest with undisturbed growth for 25 years; closed canopy forest cover; minimum, 70 to 95% of stems <10cm diameter at breast height (dbh), with remaining stems >20cm dbh; basal area 20 to 70m^2/hectare; established understory growth. Microbiology: Diverse fauna and decomposer populations

Figure 1. Optimal locations worldwide for a tropic test facility (after King *et al.*, 2004a)

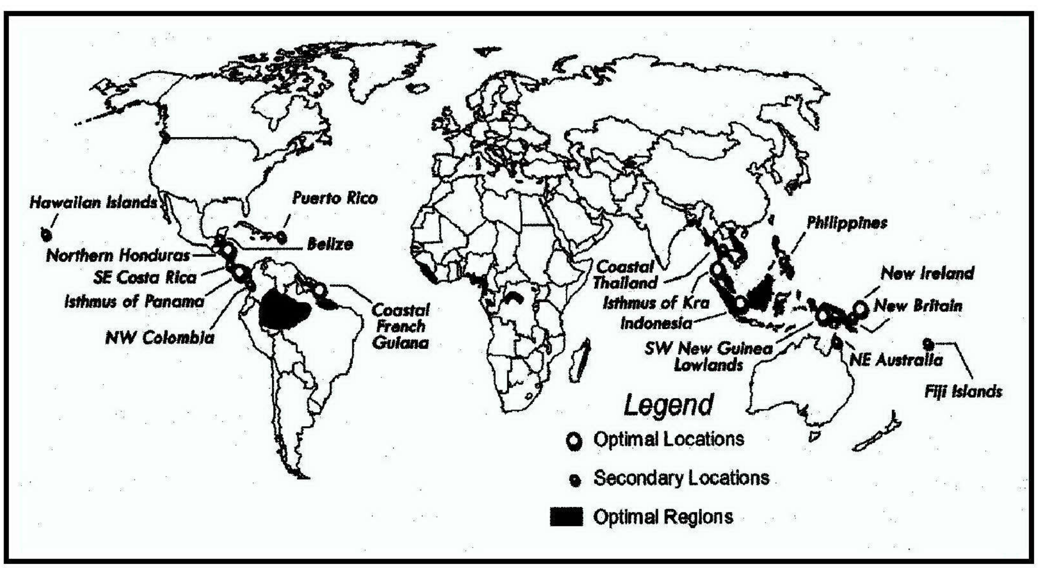

Table 4. Environmental Factors Required for Specific Tropical Testing Missions

Mission	Environmental Factors (critical factors denoted in italics)
Equipment Developmental Testing:	
1) Communication & Electronics	*Understory, canopy, temperature*, humidity, relief, fauna
2) Ground & air sensors	*Canopy, understory*, temperature, humidity, rainfall
3) Chemical & biological defense	*Fauna, understory*, temperature, relief
4) Environmental exposure	*Humidity, rainfall, fauna, temperature*, canopy
Operational and Human Performance Testing	
1) Individual soldier systems	*Temperature, humidity, canopy, understory, rainfall, relief*, slope, soils
2) Communication and electronics	*Canopy, understory, fauna, temperature, humidity, relief*, rainfall
3) Ground and air sensors	*Canopy, understory*, temperature, humidity, relief, soils
4) Chemical and biological defense	*Understory, fauna, temperature, humidity*, relief, canopy
Small Caliber Munitions Testing	
1) Exposure testing	*Land use, temperature, humidity fauna*, rainfall, canopy
2) Operational testing and firing	*Land use, adjacent land use*, temperature, humidity
3) Smoke and obscurants	*Understory, temperature, humidity*, relief, canopy
Large Caliber Munitions Testing	
1) Exposure testing	*Land use, temperature, humidity, fauna, rainfall*, canopy
2) Operational testing and firing	*Land use, adjacent land use*, temperature, humidity,
3) Smoke & obscurants	*Understory*, temperature, humidity, relief, canopy
Coastal Exposure Testing	*Sea spray*, temperature, land use
Vehicle Mobility Testing	*Soils, slope, relief, rainfall, streams*, understory, humidity

Table 5. Critical Element Environmental Factor Rating

Grade	Environmental Ranking	Site Evaluation Description
A	All 3s	Acceptable testing capability
B	Mostly 2s	Adequate with some limits
C	2s and 1s	Marginally useful for testing
D	Mostly 1s	Undesirable, limited utility for testing (with 0 for non-essential elements)
F	Os for critical elements	Completely unacceptable

canopy (25m), secondary forest, eucalyptus forest and scrub forest with well-developed understory, occupy the area. Based upon the rating for the 14 criteria and rating scheme of Table 5, the respective grades for Schofield Barracks for the four test missions of 'Equipment Development,' 'Human Factors Testing,' 'Munitions Testing,' and 'Other Testing & Training' are B, C, B, and B. As an example of exactly how these grades were developed, consider evaluation of 'Vehicle Mobility' testing at the Schofield Barracks site, which is graded as A, for an acceptable test capability. The analysis begins with Table 4, which lists *soils, slope, relief, rainfall, and streams*, as the critical environmental factors for this test. Table 6 shows that all five parameters at this site have a rating of '3'; therefore, the presence of all the necessary critical environmental conditions yields an' A' grade for this site, for this test mission.

Table 6. Environmental Evaluation of Schofield Barracks, HI

Evaluation Criteria	Rating
Temperature	1
Rainfall	2
Humidity	2
Soils	3
Area size	3
Slopes	3
Relief	3
Surface streams	3
Understory	2
Forest Canopy	2
Forest floor fauna	2
Land use/Ownership	3
Adjacent land use	3
Cultural/Historical	3
TOTAL	35

A similar comparative evaluation process was applied to 8 sites in Hawai'i and 4 in Puerto Rico, in which the 12 sites were evaluated for 17 different test missions (King *et al.,* 1999). The results of this tropic test study include a regional analysis of the environmental setting for both Hawai'i and Puerto Rico, an environmental characterization of 12 sites, the rating of each site's capacity to support each component of the testing mission, and finally, conclusions as to the capacity to conduct tropical testing and training in these locales. The detailed regional analysis (King *et al.,* 1999) confirmed the finding of the first study report (King, *et. al.,* 1998, 2004a) that these islands offer only limited capability to support the full requirements for US Army tropical testing. Most critically, they are too far north of the tropics to have the higher temperatures specified. Further, adequate rainfall generally occurs only with orographic lifting which, in turn, also produces adiabatic cooling so that sufficient rain occurs mainly higher in the mountains where temperatures are cooler. Overviewing the site characterizations, a general absence was observed of the biological settings rated best for tropical testing, again driven by lack of temperature and/or rainfall. No double or triple canopy forests were found. A combination of factors result in the biologic web and level of diversity being greatly reduced from those seen in true tropical settings, very important aspects of sensor and electronics testing.

In summary, the ideal climate for a tropical test facility would lie in the wet tropical regime, to provide extremes of high humidity in a very high rainfall and high, constant warm temperature environment, but removed from the deleterious effects of experiencing tropical cyclones. As such, the area encompassing the site should have annual precipitation in excess of 2000mm, monthly-averaged minimum temperature in excess of 18-20^{o}C, and mean monthly temperatures and humidity of at least 25^{o}C and 75%, respectively. Rainfall in any single month would not fall below 100 mm, nor exceed 6000mm/yr. These precipitation requirements address a desire for minimal seasonal variability (preference for no absolute dry season). The ideal physical setting would be found near a coastal plate boundary tectonic setting that offers a combination of beaches, coastal landforms, and interior lowlands, yet relatively free from frequent natural hazards. It should also be a margin that is not highly active tectonically. There should also be an absence of karst topography. The soil type and structure should follow with the climate and primary physical criteria. The biological criteria are dependent on the climate and the geology, absent adverse human impacts on the area. It was estimated that 25 years of secondary growth in a tropical climate would be sufficient to restore a tropical rainforest to a stage adequate to consider the biological setting ideal. Further, a continental or large island setting is preferred to provide the diversity of species characteristic of an ideal and healthy environment. This is necessary to allow for continued regeneration of an area being stressed by testing activities. Based on a composite of the criteria from climate, physical setting and biota, 16 areas around the world were identified that met these criteria. No location under US jurisdiction met all of the essential criteria, leading to an operational decision by the Yuma Proving Ground Tropic Regions Test Center to adopt a 'catalog-of-sites' approach to meet its current tropic testing needs.

3.2 The Desert Study

A scientific analysis of the second of the three extreme environments important to a globally deployed Army, the desert environment, was conducted subsequent to the tropic study (King *et al.,* 2004b). The overall goal of the desert study was to expand current understanding of how to characterize the desert environment in ways that support the needs of the Army from testing, through training, to worldwide operational deployments.

The unique physical landscape of desert regions presents military forces with environmental challenges that differ significantly from those of other environments. Desert aridity for example, makes the availability and quality of fresh water sources of critical importance. High intensity insolation and hot temperatures with strong diurnal changes challenge both troops and equipment. The ferocity of hot desert winds and accompanying dust wreaks havoc on equipment and can stop military operations altogether at times. The unique character of desert terrain with its scarcity of vegetation and long-range visibility has tremendous impacts on tactics. A cursory examination of challenges experienced during the Persian Gulf War in 1990-91, in Afghanistan in 2001-03, and in Iraq during 2003-04 reveals perplexing data that demonstrate a need for continued emphasis on training and high quality equipment testing in these harsh regions. Further, deserts are fragile environments when subjected to human activity, and military training and testing are certainly activities that can cause long term change to a desert. These changes may make altered areas less useful as testing or training sites. The Army lacks the scientific data needed to analyze which parameters are significant for military applications. This information could help decision makers to develop programs to better sustain training lands while still providing realistic training opportunities.

Desert is a general term describing a geographic region that has a relatively dry climate, high evaporation rates, and sparse to no vegetation. The exact measures that define a desert such as levels of rainfall, temperatures, and vegetation density are not well established. Regardless of where one draws the

exact boundaries of the world's deserts, these regions are very important militarily. It was the initial hypothesis of this study that, for military testing, training, and operations, all deserts are not alike and that understanding these differences is of critical importance in planning for the world-wide mission of the US Army.

The full scope of characterizing deserts is a significant undertaking and this research was restricted to the consideration of hot and warm deserts only. The procedure followed was somewhat similar to that developed for the ideal tropic test site analysis (King *et al.*, 1998, 1999, 2001, 2004a). The first phase of research differentiated between deserts using climatic, physical and biological parameters that are relevant to military, testing, training, and operations. This approach differs from many previous works in that the key to deriving the differentiating parameters is that they have an effect on military testing, training, and operations. Consider, for example, the impacts of blowing sand and dust. This phenomenon is a common problem in the operation of military vehicles, aircraft, and weapons in the desert, but each desert is different in the quantity and type of sand and dust that may be entrained by blowing winds. Geology determines the chemical character of the fine-grained particulate materials available, whereas weathering and erosional processes affect the amount and size distribution of particulates. Each desert will have a different potential to generate sand and dust based on the magnitude of the aeolian processes, and each can impact military operations in a different way. The range of effects can be from minor annoyance to expensive damage and malfunction of equipment. It is the importance of these effects on military applications that drove the inclusion of this parameter into the analysis.

The second phase of analysis refined the process used on a world-wide scale to determine a more limited number of parameters that better describe deserts in the context of military use. Finally, the last phase of analysis verified the model through its application to YPG and NTC, providing insight into the similarities and differences between these key Army testing and training areas, and potential operational areas worldwide.

Key findings from the world scale analysis of hot and warm deserts strongly supported the initial hypothesis that deserts differ greatly in the context of military use, and understanding these differences is of critical importance to a military force that may deploy to any area worldwide. Unfortunately, data characterizing deserts at the global scale can only provide generalized, summary analyses. It is necessary to conduct more detailed investigation and to key on parameters that impact most notably on US Army testing, training, and operations requirements. The refined model is illustrated in Table 7.

The final phase of analysis applied the model to YPG and NTC. Findings suggest that while neither of these installations provides perfect analogs to other hot and warm deserts in the world, there are parameters in each that could satisfy portions of the testing and training mission for the US Army. YPG for example, offers a variety of landforms and surface features within this extreme climate that makes it an ideal setting for a large variety of military testing requirements. The installation is located in a hyperarid, extremely hot desert. Based on climate, it is the best analog to the world's hottest deserts including the Arabian, Saharan, Thar, and Australian, as well as the region of Iraq between Basra and Baghdad. Desert environments missing from YPG are large sand accumulations such as are found in the Rub-Al Khali, and sandy river plains. However, small-scale testing can be accomplished on the limited sand dunes at YPG and large-scale dunes are available for limited testing programs in BLM lands just west of Yuma, AZ. There are three major types of vegetation at YPG including taller scrubs. This taller vegetation, with limited trees, is generally located within ephemeral stream beds (*i.e.*, wadis) and offers training opportunities absent from the NTC, where larger desert vegetation is essentially absent. Further, YPG possesses an abundance of stony surfaces (desert pavement).

NTC is located in an arid, warm desert. This area generally fails to offer the temperatures seen in the world's hottest deserts. The expansion areas proposed for the NTC considerably increases the diversity of landforms and soil types available for training or testing. The desert environments missing from NTC are large sand accumulations and sandy river plains. There are three major types of vegetation at NTC including small scrub type vegetation. The NTC lacks natural areas to produce large-scale dust events. However, denuding of vegetation and destruction of surface crusts through years of continuous military training activity has created significant sized areas where operationally generated dust can mimic levels of dust seen most recently during operations in Afghanistan and Iraq.

Neither YPG nor NTC have a high frequency of natural dust storms. Surface scars from disturbance and human induced dust from training and testing activities does provide some ability to test and train in these conditions, but prolonged periods are not seen in any of the southwestern deserts. Overall, a large proportion of the natural conditions found in deserts worldwide can be analogued at YPG, NTC, or both.

Table 7 - Geographic Parameters For World Desert Model

Parameter	Description
Relief and landform	
• Bedrock highlands	Steep upland terrain and exposed rock
• Alluvial fans and pediments	Large sloped fans. Strongly dissected by deep stream beds
	• Pediments/Alluvial Fans with High Degree (>50% Surface Area) of Stone Mantles
	• Pediments/Alluvial Fans with Medium Degree (25-50% Surface Area) of Stone Mantles
	• Pediments/Alluvial Fans with Low Degree (< 25% Surface Area) of Stone Mantles
• Desert flats and plains	Minimal slope
• Sand accumulations	Dunes
Climatic	
• Temperature	Warm is > 20°C average annual daily high temperature Hot is > 30°C average annual daily high temperature
• Rainfall	Extremely dry < 100 mm, Dry < 200mm
• Wind	Winds capable of suspending dust common
Biologic	
• Vegetation largely absent	
• Sparse vegetation	• Vegetation mostly > 1 m or Vegetation mostly <1 m
Landuse	
• Area	Total area of installation
• Surrounding land use	Ownership and use of lands adjacent to installation
• Endangered and threatened species	Presence or absence
• Sustainability	Capability to continue current missions over time

The objective of this desert research was to increase the Army's understanding of the desert environment and knowledge of how this environment impacts the Army mission. The militarily significant parameters of climate, physical setting, and biotic domain were defined. The model was proven as a useful tool for analysis through application to characterizations of YPG and the NTC at Ft. Irwin. Future applications of this model and analysis process could include any geographic location studies, such as basing studies for returning units from overseas and base realignment and closure studies. The power of this method is that it ties operational needs to the geographic setting through scientific criteria.

4. CONCLUSIONS

The challenges facing the US Army require that our equipment be tested and our troops trained under the harshest and most realistic conditions possible. Environmental testing of equipment, as well as operational training of our soldiers, necessitates detailed understanding of the environments in which they are expected to operate. The closure of the Tropic Test Center in Panama and the need to better understand desert environments in a military context required the development of geographic methodologies to enhance our understanding of both tropical and desert environments. This research provides scientifically-derived models that can be used to locate nearly ideal tropical testing locations worldwide and desert analogs for testing and training that compare favorably to potential operational locations worldwide.

REFERENCES

King; WC, Harmon; RS, Bullard; T, Evans; J, Juvik; J, Johnson, R, and Larsen, M, 1998, A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems," Army Research Office, Technical Report, 47p.

King; WC, Harmon; RS, Bullard; T, Evans; J, Juvik; J, Johnson, R, and Larsen, M, 1999, A Technical Analysis of Hawaii and Puerto Rico for Tropical Testing of Army Materiél and Systems: Unpublished US Army Research Office Technical Report, 74p.

King; WC, Palka, EJ, Harmon; RS, Juvik, J, and Hendricks, JMH, 2001, A Technical Analysis of Australia for Tropical Testing of Army Materiél and Systems, Unpublished US Army Research Office Technical Report, 57p.

King, WC, Palka, EJ, and Harmon, S, 2004a, Identifying Optimum Locations for Tropical Testing of United States Army Materiél and Systems: Singapore Journal of Tropical Geography, 25: 92-108.

King, WC, Harmon, RS, Mc Donald, E., Redmond, K., Gilies, J, Doe, WW, Warren, S, Gilewitch, D., Morrill, V, Stullenbarger, G, and Havrilo, L., 2004b, Scientific Characterization of Desert Environments for Military Testing, Training and Operations: Unpublished US Army Research Office Technical Report, 111p.

U.S. Army Regulation 70-38, 1979, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions.

Winters, HA, 1998, *Battling the Elements*, Johns Hopkins Press, Baltimore, MD, 317p.